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Water Yield Estimation in a Tropical Watershed using Remote Sensing and SEBAL Model

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Abstract

Water yield information helps in determining water surplus or water deficit on certain duration of time. The use of remote sensing techniques to estimate water yield is getting popular, particularly in developing countries. This gives a new injection to the management of water resources by knowing the amount of water in a watershed area. The objective of this study is to measure the daily and monthly water yield in Triang watershed. The Surface Energy Balance Algorithm for Land Model (SEBAL) is integrated with remote sensing data to estimate water yield in Triang watershed, Malaysia. Actual rainfall and evapotranspiration parameters are used in the water yield estimations. Rainfall data is collected from the Department of Meteorological Services and Tropical Rain Measuring Mission (TRMM 2A25). While, actual evapotranspiration is extracted from Landsat-7 Enhanced Thematic Mapper Plus (ETM+) satellite data using SEBAL model. The highest potential evaporation value of the SEBAL Model is 7.04 mm/day. Results show that the highest daily water yield was recorded was 6.56 mm, while the lowest was 1.42 mm. On the other hand, the highest and lowest monthly water yield were 38.59 mm and 33.44 mm, respectively. The research results can help the local water agency and government department in handling water resources in Malaysia.

Keywords: Water yield; Evapotranspiration; Remote Sensing; TRMM; Hydrology.

1. Introduction

Understanding of local water resources is an important step in ensuring the continuous development of social-economic and industrial. Water yield information is vital to water engineer to develop a better water resources management system [1]. Forest is the best land use to maximize the water yield in a region.

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For instance, retaining the forest area in the upper of a watershed would ensuring sufficient water supply for agricultural activities in the middle or lower watershed. Therefore, understanding the relationship between water and forest is essential for planning a better water resources management system. Malaysia has a forest area of about 55% of the total land area, with total annual precipitation varies from 1800 mm/year to 4000 mm/year. Combination of huge forest area and high amount of annual total precipitation enable Malaysia to become one of the countries equip with high water yield productivity. The rain water flows into rivers from forest region in the upstream area. The water is store in dams to generate electricity and to supply freshwater for public and agricultural purposes. For example, the first dam in Peninsular Malaysia is the Sultan Abu Bakar power station in Cameron Highland.

The fields of science and technology are used to better understand the features of water. The use of remote sensing techniques to estimate water yield is getting popular, particularly in developing countries. This gives a new injection to the management of water resources by knowing the amount of water in a watershed area. It is an alternative step for managing water supply problems to consumers. The use of remote sensing techniques is an important alternative and can help solve problems faced by conventional methods. However, the early stages of the use of remote sensing techniques in this field use low-resolution spatial data such as NOAA AVHRR data of 1 km x 1 km.

The Surface Energy Balance Algorithm for Land Model (SEBAL) is integrated with remote sensing data to estimate water yield in Triang watershed, Malaysia. The focus of this study is to enhance water yield estimation method using remote sensing techniques. The specific objectives of the study are: (1) to calculate the water yield through a combination of remote sensing techniques and mathematical methods; (2) to measure the evapotranspiration value using Landsat-7 ETM + data; and (3) to determine the accuracy of actual evaporation values influenced by bio-physical parameters such as temperature, energy balance, angina speed and relative humidity obtained through the SEBAL Model. The research results can help the local water agency and government department in handling water resources in Malaysia.

1.1. Study Area

The study area is located in the Triang watershed area (latitude 2° 59' N and longitude 102° 19'E). It has an area of 210,131,106 hectares (Figure 1). The study area is located at the borders of two states namely Pahang and Negeri Sembilan. It is one of the Malaysia's main water source watersheds. This watershed covers a tropical rainforest area of 120533.4 hectares comprising primary and secondary forest types. The topography of the watershed varies from 30 to 60 m above mean sea level.

Triang watershed has a uniform temperature between 26.7 °C - 35.0 °C and high humidity [2]. In addition, the area also has a weak breeze, cloudy and receives sunlight throughout the day, with an average of 6 hours/day. The study area is influenced by two main monsoons, called the Northeast Monsoon and Southwest Monsoon. The Southwest Monsoon takes effect in May and ends in September. At present, wind blows at a speed of 15 knots. While Northeast Monsoon takes place in November and ends in March. During this monsoon, the prevailing winds are from east or northeast with speeds of between 10 and 20 knots. In particular, rainfall is dominated by the convective rainfall that falls during the year. The record shows the minimum annual rainfall recorded above 1500 mm.

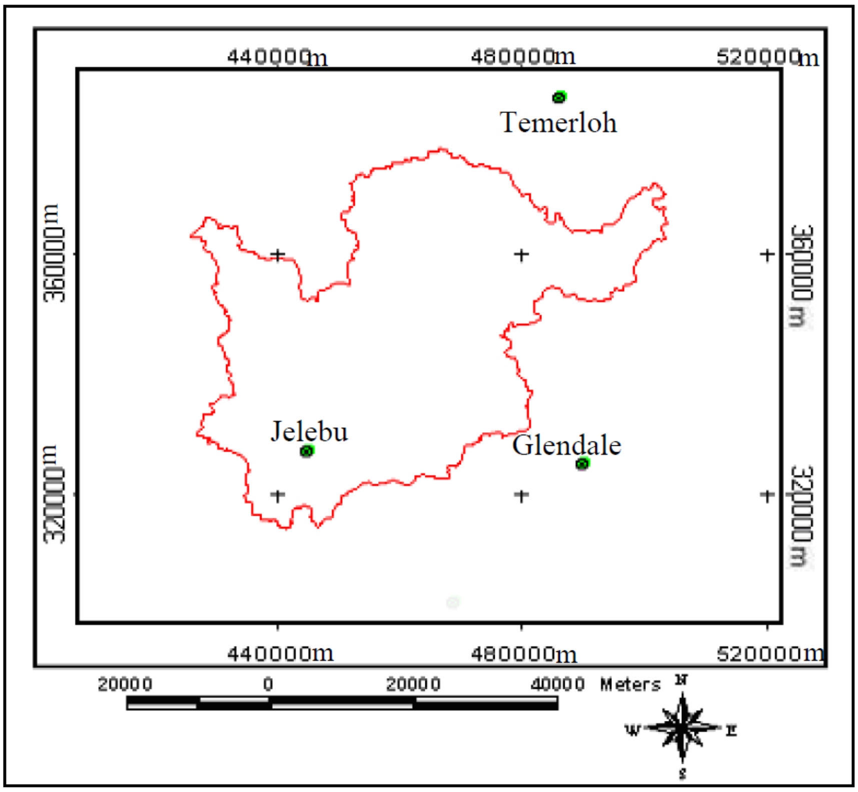

Figure 1: Study Area.

1.2. Materials

Two sets of Landsat-7 ETM + data taken on 11 February 2002 and 14 July 2002 were used in this study. Tropical Rainfall Measuring Mission (TRMM) level 2A25 product is used to extract rainfall information of the study area. It is a free satellite rainfall data. Basically, TRMM data is a combination of microwave sensors, visible and infrared rays. There are 5 types of sensors used: Precipitation Radar (PR), TRMM Microwave Imager (TMI), Visible Infrared Scanner (VIRS), Lightning Imaging Sensor (LIS) and Cloud and Earth's Radiant Energy System (CERES). Some studies have shown that TRMM rainfall data has high accuracy in the calculation of rainfall in Malaysia (Tan and his colleagues 2015 and his colleagues 2017; Tan and his colleagues 2018).Weather data is obtained from Temerloh, Jelebu and Glendale Meteorological Station. The location of this meteorological station is shown in Figure 1. Only Jelebu Station is installed within the Tring watershed. So, Temerloh and Glendale stations are also needed because they are closest position to the study area.

2. Methodology

The methodology of this study can be divided into three phases: (1) pre-processing; (2) post-processing; and (3) calculation of the water yield. The first phase is pre-processing of Landsat-7 ETM + data, including atmospheric correction, topographic correction, geometric correction, image subset, radiometric enhancement, cloud removal and image mosaic. The second phase involves the extraction of evapotranspiration values from Landsat-7 ETM + data via the SEBAL Model. The last phase is to estimate the total amount of water yield by finding the differences between evapotranspiration (Landsat-7 ETM+) and precipitation (TRMM).The COST model, a simple atmospheric correction is used in the atmospheric correction of Landsat-7 ETM data [4]. The COST model is a combination of atmospheric correction processes and radiometric calibration. It is formed to calculate the effects of atmospheric processes such as absorption and dispersion. The Lambertian model is used in the correction of the topographic data of Landsat. This model can correct the gradient and aspect in the data used. Geometric correction is done using image reflectional techniques to maps the two Landsat-7 ETM + data used. The first polynomial degree with 3 Ground Control Point (GCP) is used to correct the images. Next, we used the nearest neighboring method to resample the images. The subset of the image is executed to cut the image of the study area by separating the image out of the area of both Landsat-7 ETM + data after geometric correction. The main element in this process is the coordinate value of the study area. This co-ordinate value is important in determining the location of the study area and it consists of four main values of top left corner X, upper left corner Y, bottom right vertex X and right bottom vertex Y. However, the coordinate values of the study area are displayed after the image mosaic process run. Cloud removal is a process to mask the digit numbers that are identified as clouds. Cloud cover often occurs in tropical climates especially in Peninsular Malaysia. This situation affects the accuracy of the results of the study. The main step for cloud mapping process is to create an image of the cloud. Cloud image formation using the first lane in Landsat-7 ETM + data. This is because these strips illustrate clearly cloud images over other strips. The mosaic process is a process of combining into two geometrically corrected images based on a common coordinate system to form a larger image or a new image. Land-use classification process was carried out on Landsat-7 ETM + data. There are several categories of land use that are determined in this study such as livestock, rice and mixed crops, oil palm, rubber, forest (primary and secondary forests) and grass or bush. After that, a sampling technique is conducted randomly. It is depending on the size of the land use types. The total number of sample points is proportional to the land use size. It means wider the land use area, greater the number of sample points required. There were 36 sample points used in this study (Figure 3). This study uses the SEBAL Model to get the real error rate. The main advantage of this model is to assess the real error for each surface via pixels to remote sensing data pixels.

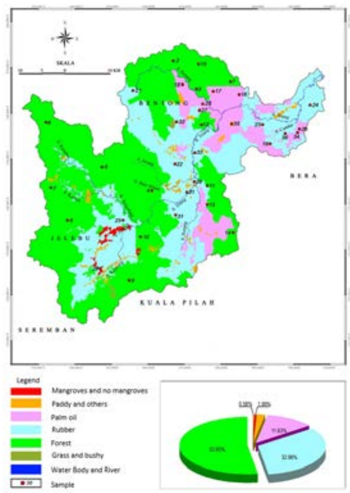

Figure 2: Land use map of Triang watershed.

3. Results and Discussion

3.1. Landsat-7 ETM

The process of selecting suitable bands layers is done by determining the pathways in this data. It is important that band definition affects the entire process involving the use of this data. After that, the atmospheric correction process, topographic correction and geometric correction are performed for both Landsat-7 ETM + data. The vector map of Peninsular Malaysia with scale 1: 100000 is used to determine the accuracy of the geometric correction process. The image subset process is executed to remove the numerical values of the marine area for these two data.

Histogram adjusting methods are performed for the radiometric improvement process. This method uses data dated July 14, 2002 as reference data for data dated February 11, 2002. The accuracy of the radiometric increase process using R square analysis (r^2) to show the strength of the value relationship to these two data. This analysis is determined by each band for these two data is shown in Table 1. Referring to Table 1, the highest r^2 value approaches value 1 is at band 7 of 0.998 while the lowest is at band 3 of 0.916. The r^2 average value of all the paths is 0.969. This indicates that it has a very high relationship strength between the values to the two data. After all pre-processing is carried out, the Landsat-7 ETM + data image is displayed through Figure 2. There are 36 sample points that have been determined by land use in the study area. At each sample point, the value of each parameter in the SEBAL Model, rain and water yields are determined.

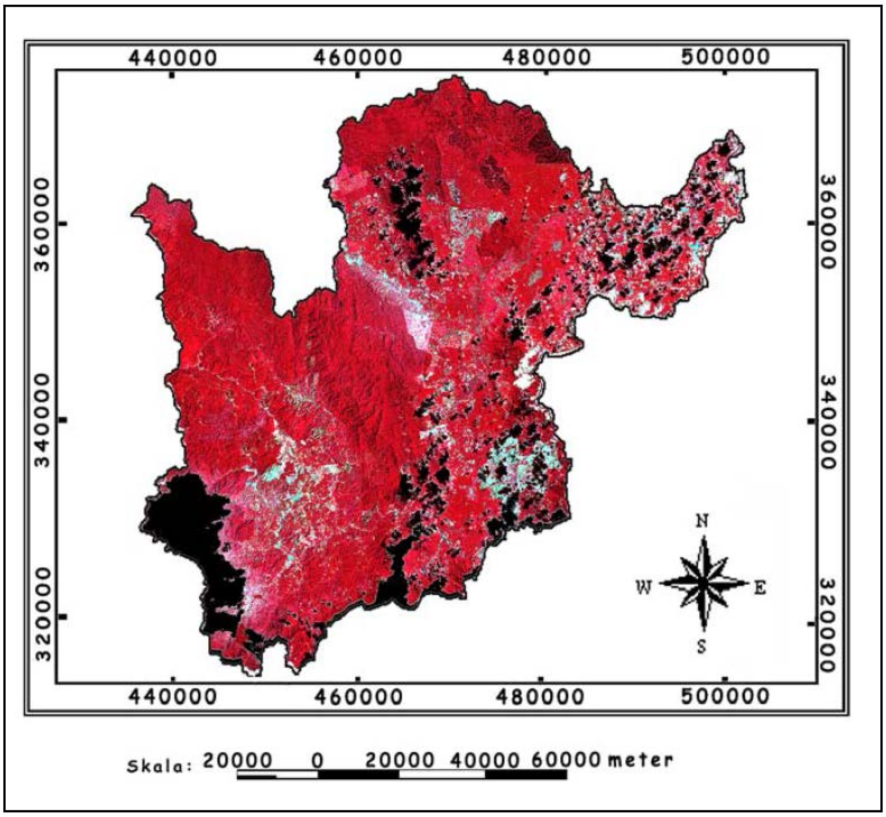

Figure 3: Landsat-7 ETM of Triang Watershed.

Table 1: Statistical analysis of radiometric corrections of Landsat-7 ETM+ data

Band	r^2
1	0.976
2	0.928
3	0.916
4	0.993
5	0.980
6	0.996
7	0.998

3.2. SEBAL model

The analysis focuses on the overall mean value of the image and 36 sample points (primary forest, palm oil, rubber, etc.) for each parameter. The results can be referred to Table 2. This comparison refers to the studies conducted in Pasoh Forest area [2], Malaysia [5] and Amazon forest [6]. Although they differ in dates, the values obtained from previous studies can be compared to the physical characteristics of the study area. The comparison of values used for surface albedo is the value obtained by [2] of 0.118. It is different 0.001 with the obtained from this study for an average sample point for primary forest area of 0.119. The average value of NDVI obtained in this study was 0.58 and it was within the specified value space for forest area of 0.5 - 0.6 [7]. For the average value of the sample point for the primary forest area, it varies by 0.02 from the range of the space. The average emissivity value of this study was 0.979. It is within the range of values of 0.96-1.00 which has been set for the tropics by NASA. The average surface temperature value obtained from this study was 295.556 K. It was different from 4.29 (11 February), 3.39 (14 July) which was observed at Temerloh Meteorological Service Station, 4.24 (11 February), 5.89 (14 July) at Service Station Glendale Meteorological and 4.54 (11 February), 5.84 (14 July) at Jelebu Meteorological Services Station. The average value obtained by the radiation radiation parameter in this study was 317.603 W/m^2 and only differed from 17.603 W/m^2 obtained from [2]. The average value of the soil heat flow obtained varies from 3.774 W/m^2 obtained by [6]. This shows that this value is suitable for tropical climates. For the heat flow of taste, it shows a difference of 6.555 W/m^2 obtained from the value obtained from [2]. For the latent heat flow value, the value obtained in J / kg units as required by the SEBAL Model. However, it was compared with the value in W/m^2 obtained from [2] of 200.0 W/m^2. The average value is used for this parameter. The value obtained is 194.339 W/m^2. It differs from 5.661 W/m^2.

The highest potential evaporation value of the SEBAL Model is 7.040 mm/day. The lowest value derived from the Turc formula is 0.98 mm/day. This shows that the amount of rain that falls on the day is less. The Thornthwaite formula shows a value of 2.190 mm/day on February 11 and 6.291 mm/day on July 14. This value variation refers to a change in temperature value. The average temperature value for 36 sample points was 26.60 ^oC for February 11 and 27.38 ^oC for July 14. The results of the Blaney-Criddle formula show that February 11 was 3.437 mm / day and on July 14 was 5.392 mm / day. However, this formula relies solely on the value of the plant coefficient determined by the researcher. The appropriate formula determined to match the value with the

SEBAL Model is Penman Formula. This formula is based on the surface energy balance and the amount of sunlight. However, the value obtained from this formula is lower than that obtained from the SEBAL Model of 3.494 mm/day for February 11 and 3.002 mm/day for July 14. This shows that the value obtained varies by 3.546 on February 11 and 4,038 on July 14.

Table 2: Parameters in the SEBAL model.

Parameter	Overall Average Value	Value for each land use	
Surface Albedo	0.15	Primary Forest	0.119
		Palm Tree	0.140
		Rubber	0.168
		Others	0.202
NDVI	0.58	Primary Forest	0.602
		Palm Tree	0.627
		Rubber	0.573
		Others	0.310
Emissivity	0.979	Primary Forest	0.985
		Palm Tree	0.987
		Rubber	0.983
		Others	0.951
Surface Temperature	295.556 K	Primary Forest	295.214 K
		Palm Tree	295.553 K
		Rubber	295.814 K
		Others	296.839 K
Net Radiation	317.603W/m^2	Primary Forest	337.027 W/m^2
		Palm Tree	324.984 W/m^2
		Rubber	297.286 W/m^2
		Others	276.069 W/m^2
Soil Heat Flux	29.226W/m^2	Primary Forest	29.077 W/m^2
		Palm Tree	28.363 W/m^2
		Rubber	29.095 W/m^2
		Others	31.877 W/m^2
Sensible heat flux	93.445W/m^2	Primary Forest	92.127 W/m^2
		Palm Tree	47.114 W/m^2
		Rubber	73.409 W/m^2
		Others	102.753 W/m^2
Latent heat flux	2448098.472 J/kg	Primary Forest	2448841.483 J/kg
		Palm Tree	2448106.650 J/kg
		Rubber	2447491.200 J/kg
		Others	2445166.932 J/kg
Potential evapotranspiration		Primary Forest	7.48 mm/day
		Palm Tree	7.30 mm/day
		Rubber	6.86 mm/day
		Others	6.41 mm/day

3.3. Water yield

The results of daily and monthly water yields of 36 sample points are shown in Figure 4 and 5, respectively. The daily water yield generated using the Landsat-7 ETM + and TRMM 2A25. Figure 4 shows the highest water yield was recorded at the sample point of 15 which was 6.561 mm, while the lowest was recorded at the sample point 36 (1.415 mm). The highest water yield was recorded at the sample point 36 which was 38.585 mm while the lowest was recorded at the sample point of 15 (33.439 mm).

The main reason for the loss of water on February 11 is that the TRMM 2A25 data shows a rainfall value of 0.0 mm. At the same time, the process of water loss through actual evaporation occurs. On July 14th, TRMM 2A25 data shows a rain value of 40 mm which is higher than the value obtained by the evaporating process. It refers to the value of water derived from the actual rainfall and evaporation parameters derived from the SEBAL Model in the compact water balance model. In February, all 36 sample points experienced a reduction in water from the previous month. The sample point 15 experienced the highest water loss of 115.14 mm while the lowest was recorded at the sample point 36 ie 11.25 mm. In July, there was an increase and decrease in water yield at sample points. The sample points that experienced the increase in water in the previous month were 5, 7, 8, 10, 26, 27 and 36 and otherwise occurred in addition to the sample point. The highest increase in water yield was 64.42 mm and the highest reduction in water was 130.21 mm.

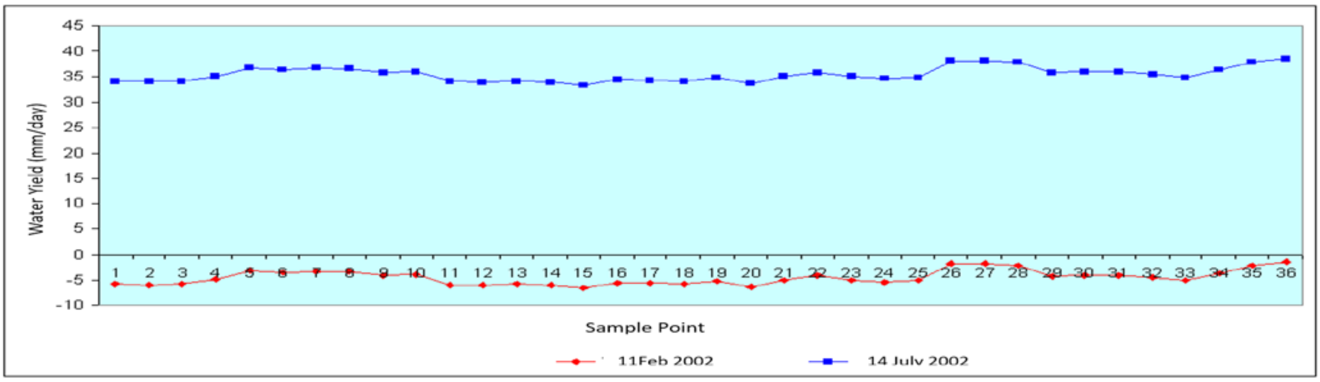

Figure 4: Daily water yield on 11 Feb 2002 and 14 July 2002.

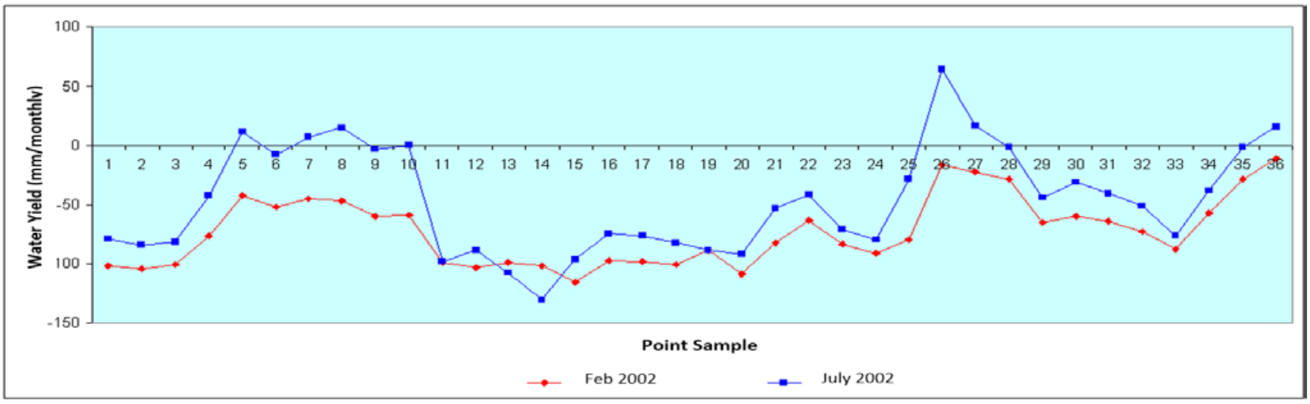

Figure 5: Monthly water yield in February 2002 and July 2002.

4. Conclusions

This study estimated the water yield of Triang watershed using remote sensing and SEBAL model. We evaluated the accuracy parameters applied in the SEBAL model by comparing with parameters of other research. All parameter parameters in the SEBAL Model are reliable. The parameters other than the real mistake in the SEBAL Model are considered as physical bio-parameters that affect the real-time value of the actual value. Thus, statistical analysis has shown that there exists a strength of value relationships among other parameters in the SEBAL Model with actual real value. From the findings, remote sensing techniques can be used to assess the water yield using a very short period.

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